Although considerable data has been accumulated on language organization in humans, the representation of language in the brain of multilingual persons remains controversial. Data from some studies have shown that different languages share the same areas of the brain, whereas other data have indicated that bilingual persons could have overlapping but also distinct cortical language areas. The question of whether the organization of these languages could be related to, among other factors, the time of acquisition of native and second languages (early or late bilingual) and the patient’s fluency in these languages (high or low proficiency) has not simplified the debate on the cerebral organization in bilingual people. These issues are important because bilingualism is present in practically every country in the world and a majority of the world’s population uses more than one language, often for different purposes.

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Object. In an attempt to gain a better understanding of how multiple languages are represented in the human brain, the authors studied bilingual patients who underwent surgery for brain tumors, during which the authors mapped cortical language sites by using electrostimulation.

Methods. Reading, counting, and word retrieval tasks were studied in 12 right-handed bilingual patients with no language deficit. All bilingual patients were native to France. One patient spoke four languages. The patients constituted a nonhomogeneous group in terms of language proficiency or age of acquisition. Languages were evaluated and classified into three major groups, depending on proficiency and date of acquisition. Specific conditions of language site validation were applied, separating typical anomia sites from speech arrest or other language sites (such as hesitation sites). A total of 30 speech arrest sites, 16 anomia sites, and three sites of language difficulties (not typically classified as speech arrest) were found throughout the 26 language studies performed.

Strict overlapping of language areas (for all language tasks) was found in five patients, whereas the remaining seven had at least one area that was language-specific and sometimes task-specific. Specific areas for a particular language were found for word retrieval tasks (anomia) in eight sites (50%) but also in six (20%) of the reading or counting sites (speech arrest), either in frontal (three patients) or in temporoparietal (four patients) regions. Among the four early bilingual patients tested (languages acquired before the age of 7 years), three had language-specific cortical areas. Interestingly, six patients in this series who had a discrepancy between two languages did not have more cortical areas devoted to the less proficient language (with acknowledgment of the limit in cortical exposure available for testing by the craniotomy).

Conclusions. In this series, the authors found that bilingual patients could have common but also different cortical areas for both languages in temporoparietal areas and in frontal areas. In some cases, the authors found that language tasks such as counting, reading, or word retrieval in different languages can be sustained by language- and task-specific cortical areas. In bilingual patients, cortical mapping should ideally be performed using different language tasks in all languages in which the patient is fluent.

Key Words • brain tumor • bilingualism • cortical stimulation • language

Although considerable data has been accumulated on language organization in humans, the representation of language in the brain of multilingual persons remains controversial. Data from some studies have shown that different languages share the same areas of the brain, whereas other data have indicated that bilingual persons could have overlapping but also distinct cortical language areas. The question of whether the organization of these languages could be related to, among other factors, the time of acquisition of native and second languages (early or late bilingual) and the patient’s fluency in these languages (high or low proficiency) has not simplified the debate on the cerebral organization in bilingual people. These issues are important because bilingualism is present in practically every country in the world and a majority of the world’s population uses more than one language, often for different purposes.

In an attempt to gain a better understanding of how multiple languages are represented in the human brain, we studied bilingual patients who underwent surgery for brain tumors. Different language areas were localized in these patients during awake surgery by using direct cortical mapping. The cortical organization of the different languages was analyzed in relation to these surgical data, and a review of the literature was performed.

Clinical Material and Methods

Patient Population

Between November 1998 and November 2001, 12 right-handed bilingual patients (eight men and four women) with a mean age of 54 years (range 30–74 years) and no language deficit were prospectively studied using cortical brain mapping. All patients were native to France. Lesions were located in the left hemisphere in all patients. Tumor types included five gliomas and five metastases originating in the frontal (middle frontal and inferior frontal gyri) or temporal regions (superior temporal and middle temporal gyri). According to histopathological studies, one glioma was low grade and four were high grade (World Health Organization Grades III and IV). One patient had a meningioma and one with a cavernoma were also studied.
TABLE 1

Language classification used in this study for bilingual patients

| L.1   | early-acquired language (before 7 yrs of age) spoken daily or frequently. The patient is able to name various objects & all sentences read by the subject are understood w/o problem. A conversation on concrete or abstract topics can be conducted by the patient. |
| L.2   | late-acquired language (after 7 yrs of age) spoken daily or frequently. The patient is able to name various objects & all sentences read by the subject are understood w/o problem. A conversation on concrete or abstract topics can be conducted by the patient. |
| L.3   | late-acquired language (after 7 yrs of age) not spoken every day. The patient is able to name various objects w/o problem. All basic sentences read by the subject are understood w/o problem. A conversation can be conducted by the patient on concrete topics. |

Languages Studied

Language classification and definitions of bilingualism are matters of debate. The definition of a “bilingual person” can include, among other factors, phonological, grammatical, semantic, stylistic, cultural, lexical, or graphic skills. A recurring problem is how to define and measure bilingualism objectively both in quantitative and qualitative terms. Clear-cut classifications are difficult because bilingual individuals are rarely equally fluent in both languages on all possible topics. In this study of a small group of patients, language was classified as an early-acquisition (before the age of 7 years and considered to be a native language), high-proficiency language (L1); a late-acquisition (after the age of 7 years), high-proficiency language (L2); or a late-acquisition (after the age of 7 years), low-proficiency language (L3; Table 1).

Using our classification system, no patient in this study was characterized as early bilingual with low-proficiency language (that is, having a serious loss of a previously acquired native language because of the acquisition of another language). Although all patients spontaneously admitted that they were right handed, the degree of handedness of the subjects was assessed using the Edinburgh Inventory.21 Handedness is assessed ranging from 100 for completely right-handed patients to −100 for completely left-handed ones by asking what hand the patient usually prefers to perform various daily acts. In our study, the handedness indexes ranged between 100 and 30, which indicated a clear predominance of right handedness in all subjects. All patients had language examinations pre- and postoperatively to rule out language-specific deficits. This testing (of all languages studied) included evaluation of written and oral understanding and naming, language fluency, reading, computing, dictation, repetition, written transcription, and object handling by using appropriate tests.23 In this study, strict inclusion criteria were used; dysphasic patients (those with more than 10% of errors in naming tests) were excluded from this study.

Languages studied were French in all patients, English in six, Spanish in two, Occitan in four, and German and Mandarin Chinese in one patient. One patient (Case 12) spoke four languages. Occitan is a regionalized French dialect spoken in the south of France, often by persons older than 60 years, which contains some words with the same roots as modern French (French and Occitan belong to the same family of romance languages) but with several words that are different. For example, in our 60-image set of word retrieval, only seven words (12%) were strictly similar to French and 21 words (35%) differed by one suffix only; another 32 words were either completely different or differed by more than one suffix.

During surgery, all patients were asked to complete three different tasks in the appropriate language: a counting task (that is, “1, 2, 3, 4, 5. . . .”), a naming task to search for a standard anomia (that is, “This is a. . . .”), and a reading task with various sentences. Counting is a basic task in brain mapping that can be related to automatic speech (as in calendar sequences or series of letters). Word retrieval and reading tasks are more elaborate tasks known to activate similar or different areas in the brain. The word retrieval task is based on the fact that at the core of language formation lays the ability to find the word that conveys the meaning of a given thought or object. The reading task involves, among other components, a more specific functional component, that is, the orthographic lexicon. All patients and their families gave their informed consent to study their language areas by direct brain mapping.

Cortical Mapping Procedures

Patients all underwent operation with the awake surgery technique.19 Three-point head fixation was applied. We used a neuronavigational system in all but one patient (Case 12). The brain was exposed in a standard fashion. Intraoperative cortical stimulation was used to localize areas of functional cortex after determining the afterdischarge threshold by performing electrocorticography. The cortex was directly stimulated using the bipolar electrode of the Ojemann cortical stimulator (1-mm electrodes 5 mm apart; Radionics, Burlington, MA). The amplitude of the current was progressively increased by 1 mA, beginning at 2 mA. We used a standard procedure of stimulation with biphasic square wave pulses of 1 msec at 60 Hz, with a maximum train duration of 4 seconds. When a functional site was found, it was marked with a sterile 0.25-cm2 ticket, and another area 5 mm away was tested. To spare functional areas found using this test during tumor removal, we adopted a policy of resecting the tumoral tissue no closer than 1 cm from eloquent cortex (distance of the resection margin from the nearest functional site).

Conditions of Validation of Language Sites

To be considered as a language location, each language site found was meticulously tested at least three times. Sites showing no reproducible anomia or speech arrest were not included in this study. To detect wrong answers, patient answers were checked by a person who understood the second language spoken by the patient. Languages were mapped sequentially; that is, the entire exposed cortex was mapped first in one language and then in another. Although debatable, we chose to designate language locations as having one of the following three patterns: 1) typical anomia, in which the subject said “This is a. . . .” but was unable to name the object; or 2) speech arrest: schematically, this effect can be due to contraction or paralyzing effects of the muscles that participate in the speech process (often seen in the rolandic cortex or just in front of it). Precentral gyrus sites producing speech arrest generally correspond with the

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articular process of speech (motor effect). Nonetheless, speech arrest can also be due to specific interference with the language process without visible face or mouth contraction (especially in temporoparietal areas). Considering that the separation of these two mechanisms can be controversial (because contractions of the larynx or pharynx muscles or the tongue cannot always be seen during brain mapping), speech arrest sites were also included in this study but not formally separated from each other. 3) Other phenomena that can be found during direct cortical mapping of language include hesitations, vocalizations, paraphasias, or neologisms. These phenomena, which cannot really be classified as speech arrest and can be found in either the frontal or temporoparietal areas, have also been considered language sites and have been marked. Intraoperative photographs of the brain were taken to show the sites of positive or negative cortical stimulation. To improve our understanding of the intraoperative pictures, cortical sites producing no language impairment (negative sites marked N) were not systematically noted with a sterile ticket. Small sterile flags representing the language studied were used in the intraoperative pictures.

Results

Overall Results

A total of 26 language studies were performed in the 12 patients. In each language study, all three tasks (naming, reading, and counting) were conducted in all but one patient (76 tasks in all). The patient in Case 6 did not cooperate well in the reading tasks in English or French. Speech arrests (counting and reading tasks) were found 108 times (30 sites) and anoma phenomena were demonstrated 25 times (16 sites) in common or different sites. Three additional repeated delays in response (not directly classified as speech arrest) were identified; one was specific to a second language (Case 5). Four anoma sites were found in frontal areas and 12 in temporoparietal areas. Among the 16 sites found during word retrieval, eight were common and eight were different (50% each). Twenty speech arrest sites (stopping counting or reading) were found in frontal areas and 10 in temporoparietal areas. Among these, 24 were common to languages spoken by the patients, whereas six were different (20%). When stimulated, six sites in the temporoparietal area were associated with specific impairment while reading (but not counting). Anoma sites were found in seven patients (Cases 1–3 and 9–12), whereas at least one site of speech arrest was found in all patients. No vocalization phenomenon was found. For all the patients in this study, the largest current that did not evoke afterdischarges ranged between 3 and 8 mA. No patient had a generalized seizure intraoperatively, but one (Case 8) developed an episode of partial seizure that was rapidly controlled by performing cortex irrigation with cold Ringer lactate fluid. Patient, histopathological, and language data are summarized in Table 2 and Figs. 1 and 2.

Specific Results

Strict overlapping of language areas (for all language tasks) was found in five patients (Cases 1, 4, 6, 7, and 9). Among these patients, one common spelling area was discovered: one patient (an English teacher, Case 1) was unable to name an object unless she spelled it (but she said afterward that she had known its meaning). For instance, seeing a tortoise drawn, the patient said “this is a T, O, R, T, O, I, Š, E”, or “c’est une T, O, R, T, U, E” in both English (L2) and French (L1). The remaining seven patients had at least one language area specific for one language and for one of the tasks studied. Areas specific to one language were found for anoma (Cases 2, 3, and 10–12), and/or counting (Cases 2, 5, 9, and 12), and/or reading (Cases 2, 3, 5, 8, 10, and 12), whether in frontal (Cases 5, 8, and 11) or temporoparietal areas (Cases 2, 3, 10, and 12).

The patient in Case 2 (French L1/Spanish L3) presented with specific zones both in naming and counting tasks in the superior temporal gyrus. In this region, a typical zone of anoma was found in French, whereas stimulation in this area did not disturb Spanish language. On the contrary, a

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**Table 2**

<table>
<thead>
<tr>
<th>Case No.</th>
<th>Age (yrs)</th>
<th>Sex</th>
<th>Diagnosis</th>
<th>Location</th>
<th>Laterality Index†</th>
<th>Languages</th>
<th>Naming Sites</th>
<th>Speech Arrest</th>
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<tbody>
<tr>
<td>1</td>
<td>48, F</td>
<td></td>
<td>meningioma</td>
<td>pterional</td>
<td>90</td>
<td>French L1, English L2</td>
<td>C</td>
<td>C</td>
</tr>
<tr>
<td>2</td>
<td>74, F</td>
<td></td>
<td>metastasis</td>
<td>postcentral gyrus</td>
<td>80</td>
<td>French L1, Spanish L3</td>
<td>D</td>
<td>CD</td>
</tr>
<tr>
<td>3</td>
<td>64, M</td>
<td></td>
<td>glioblastoma</td>
<td>T2</td>
<td>90</td>
<td>French L1, Occitan L1</td>
<td>CD</td>
<td>ND</td>
</tr>
<tr>
<td>4</td>
<td>50, M</td>
<td></td>
<td>metastasis</td>
<td>F2</td>
<td>100</td>
<td>French L1, English L2</td>
<td>ND</td>
<td>C</td>
</tr>
<tr>
<td>5</td>
<td>37, M</td>
<td></td>
<td>cavernoma</td>
<td>F3</td>
<td>80</td>
<td>French L1, English L3</td>
<td>ND</td>
<td>CD†</td>
</tr>
<tr>
<td>6</td>
<td>35, M</td>
<td></td>
<td>oligodendrogioma</td>
<td>F2</td>
<td>30</td>
<td>French L1, English L3</td>
<td>ND</td>
<td>C</td>
</tr>
<tr>
<td>7</td>
<td>62, F</td>
<td></td>
<td>metastasis</td>
<td>T2</td>
<td>100</td>
<td>French L1, English L3</td>
<td>ND</td>
<td>C</td>
</tr>
<tr>
<td>8</td>
<td>67, M</td>
<td></td>
<td>astrocytoma Grade III</td>
<td>F2</td>
<td>100</td>
<td>French L1, Occitan L1</td>
<td>ND</td>
<td>CD</td>
</tr>
<tr>
<td>9</td>
<td>65, M</td>
<td></td>
<td>astrocytoma Grade T1</td>
<td>F3</td>
<td>100</td>
<td>French L1, Occitan L1</td>
<td>C</td>
<td>ND</td>
</tr>
<tr>
<td>10</td>
<td>68, M</td>
<td></td>
<td>glioblastoma</td>
<td>T2</td>
<td>100</td>
<td>French L1, Spanish L1</td>
<td>D</td>
<td>C</td>
</tr>
<tr>
<td>11</td>
<td>55, M</td>
<td></td>
<td>metastasis</td>
<td>F3</td>
<td>80</td>
<td>French L1, Occitan L3</td>
<td>CD</td>
<td>C</td>
</tr>
<tr>
<td>12</td>
<td>30, F</td>
<td></td>
<td>metastasis</td>
<td>sylvian fissure</td>
<td>90</td>
<td>French L1, English L2, German L3, Chinese L3</td>
<td>CD</td>
<td>CD</td>
</tr>
</tbody>
</table>

* C = only common language areas found for languages tested; CD = common but also distinct areas for the languages tested; D = only distinct language areas for languages tested; F2 = middle frontal gyrus; F3 = inferior frontal gyrus; ND = not detected; NP = not performed; T1 = superior temporal gyrus; T2 = middle temporal gyrus.
† Calculated from Oldfield.‡ Zone of hesitation rather than speech arrest.

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neighboring area of speech arrest during counting or reading was found for the Spanish language. The patient in Case 3 (French L1/Occitan L1) had two specific French zones in naming (no anomia was found while performing the naming task in the second language) and one zone producing exclusively French speech arrest during reading (Fig. 3). The patient in Case 5 (French L1/English L3) had a specific site (English) of hesitation in the middle frontal gyrus during counting and reading (no problem in this area while speaking French). The patient in Case 8 (French L1/Occitan L1) had a specific site in the frontal region producing only counting or reading arrest in French. In the patient in Case 10 (French L1/Spanish L1) we found one specific site for French and one for Spanish in the superior frontal gyrus (Fig. 4) producing selective anomia and reading difficulties. Two typical anomia frontal sites specific to a second language occurred in the patient in Case 11 (French L1/Occitan L3), whereas three sites were common to both languages. In the patient in Case 12, a multilingual (French L1/English L2/German L3/Mandarin L3) woman, a specific cortical temporal site sustained English language while another temporal site, when stimulated, produced French, German, and Mandarin anomia. Reading in French, German, and Mandarin (logographic script) was disturbed in the same region (Fig. 5). Finally, at least one language- and task-specific site (for the tasks used in this study) was found in patients in Cases 2, 3, and 11.

Language Characteristics

Four patients were early bilinguals (Cases 3 and 8–10) and among them we found three (Cases 3, 8, and 10) who had distinct language cerebral representation. Whatever the level of proficiency, some patients (Cases 3, 8, and 11) showed that languages with the same linguistic roots (as in French and Occitan) can have common but also separate language areas for similar or different tasks. Six patients (Cases 2, 5–7, 11, and 12) in this series had different levels of proficiency (L1 or L2 compared with L3) in the languages tested. Among these patients and in the restricted area of craniotomy tested using electrostimulation, only one patient (Case 11) had more cortical areas devoted to the less fluent language.

Postoperative Language Evaluations

Postoperatively, we looked for language-specific deficits. Nevertheless, our policy was to spare all language areas found during cortical mapping, limiting postoperative pure language-specific deficits in our bilingual patients. Furthermore, the cortical language areas found were not necessarily in direct proximity to the resection margin. Finally, because language areas (although sometimes distinct) were located in the same regions, it was difficult to observe selective language deficits due to surgical manipulation caused by postoperative cerebral edema, for instance. Only one patient exhibited a language-specific disturbance, whereas six patients had a transient language disturbance (for both languages). Postoperative transient language-specific difficulties in the English language occurred in only one patient (Case 12) in whom the specific cortical language area was very close to (within 1 cm) the resection area (sylvian fissure).

Discussion

The question of language organization in the brain of a bilingual person has been debated for many years. One of the main issues sustaining the debate is whether different languages are located in the same cortical areas (or use the same semantic processes). Several factors could, in theory, influence this cerebral organization: 1) the age of acquisition of a second language; 2) the proficiency in the second language; 3) the degree of patient language lateralization; 4) the pattern of language used in a subject-alphabet or ideographic script, for instance; 5) the effect of train-
ing (a language cortical representation could be modified over time by training); 20 and 6) the tasks used to evaluate potential differences in language organization and different language skills of bilingual individuals (such as word retrieval, verb generation, listening to a story, or reading). 29 Regarding this latter factor, if the tasks tested are not sensitive enough, they may not show differences in the representation of languages. Furthermore, some brain imaging procedures (such as PET scanning) may be inappropriate for detecting subtle differences across languages. 29 Finally, we must also note that the cerebral organization in a patient speaking two neighboring languages (for example, languages with Latin roots [romance languages] such as Spanish, Catalan, French, Occitan, or Italian) could be different from that in a patient who speaks two very different languages such as English or French compared with Slavic or Asiatic languages. 22

The possible interaction of some or all of these factors has not simplified the debate, and studies on the exact cerebral organization of the brain in a bilingual person have sometimes produced contradictory results. Two kinds of studies allow for the examination of brain organization in bilingual individuals: clinical findings based mainly on selective acquired language deficits in patients, or pure research studies of bilingual volunteers by using brain mapping tools such as PET scanning, 14, 26 fMR imaging, 7, 10–12, 51, 36 or MS imaging. 33 Clinical observations based on actual cerebral lesions have historically been the first to pose the problem of distinct cortical areas for languages. 32 Although the former hypothesis of a greater involvement of the right hemisphere in the second language representation has been contested, 18, 24, 37 selective impairments in and/or recovery of only one language in bilingual persons have been observed for a long time. The first known description of a dissociation in reading in different languages in a bilingual person is probably the description made by Johann Gesner in 1770. He described a bilingual (Latin and German) man with a speech impairment who was able to read Latin better than German and who recovered best in the former language. In 1843, Jacques Lordat reported on the case of a bilingual (Occitan and French) priest, a native of Languedoc (Southern France). This man was affected by a massive selective deficit in French, whereas his Occitan was unaffected. Lordat also gave the first autobiographical account of a “differential” dyslexia, saying that after he had suffered a stroke he was unable to read properly because “syntax had disappeared. The alphabet alone was left to me, but the function of the letters for the formation of words was a study yet to be made. I had to spell out slowly most of the words.” This account is strikingly similar to the spelling symptoms of our patient in Case 1 following stimulation of one temporal lobe site. These cases of dissociation or spoken language loss in bilingual persons were followed by other cases described throughout the 19th century, 2, 34 and more recently, 7, 15, 22, 32, 35 in reading, 15, 35 speech expression, 2, 15, 16, 34 or comprehension. 7, 15, 32 Cases of dissociation in writing have also been described when the language used had a different writing system, as in Japanese Kana or Kanji characters. 35 Finally, in 1895, the pioneer of studies in bilingual persons, Pitres noted that it was in the language with which the patient was the most familiar that the subject recovered best (the Pitres law). All these observations about selective impairment or recovery have led to the hypothesis that multiple languages could be represented, at least partially, in different brain areas.

Nevertheless, some authors have claimed that acquisition
of a new language does not require a new semantic processing or new cortical areas.3,9–12,14,25,31 Chee, et al.,3 studied 24 volunteers who spoke Mandarin Chinese and English (15 had learned both languages before the age of 6 years and nine had learned them after the age of 9 years) by using fMR imaging, which demonstrated that there was no significant difference in both cortical language organizations despite the age of language acquisition. Klein, et al.,12 studied 12 patients who were bilingual in French and English by performing PET scanning, and found no difference in brain activation during word processing, except a left putaminal activation present in the second acquired language. Hasegawa, et al.,9 examined individuals who were bilingual in Japanese and English and found that shared cortical regions were activated during processing of both languages, although greater activation was found when the task in the second acquired language increased in difficulty. Illes, et al.,12 used semantic judgment tasks to demonstrate no difference in cerebral activation on fMR images obtained in eight patients bilingual in English and Spanish. Persons bilingual in English and Spanish were also studied using fMR imaging by Hernandez, et al.10,11 Six patients were classified as early bilingual, having learned both languages before the age of 5 years. The authors found that activations in both languages during naming tasks (of objects or actions) were located in overlapping areas of the brain.

In contrast, other researchers have found that bilingual patients used shared but specific cortical areas for different languages.13,20,27,29,30,33 Perani, et al.,27 have shown by listening to stories that the cerebral organization of the brain in a bilingual person was more influenced by attained proficiency than by age of acquisition; that is, persons with low proficiency have different cortical responses more often, whatever their age at the time of second language acquisition. The possibility of finding different sites of language in bilingual persons as well as larger cortical areas in the language in which the patient was least competent has been noted by Ojemann and Whitaker20 by using direct brain mapping in two patients. This hypothesis has been supported by Yetkin, et al.,36 who found, by using fMR imaging in five patients, that more cerebral areas were recruited in a person who was not fluent than in a person who was fluent. Kim, et al.,13 have separated bilingual organization in frontal areas from those in temporoparietal areas. The Broca area could contain more distinct language areas in patients who acquired a second language later in life, whereas language receptive areas showed little difference among language representation. More recently, Pouratian, et al.,29 in studying one bilingual patient (Spanish and English) by using optical imaging, identified common but language-specific areas in the supramarginal gyrus (in Spanish) and, surprisingly, because it is a primary motor area, also in the precentral gyrus (in English). Finally, Simos, et al.,33 have studied the receptive language cortical areas of 11 healthy bilingual (English and Spanish) adults with the aid of MS imaging.33 They also found differences in cortical representation of both languages in the temporal areas. Despite these advances in knowledge in recent years, the data presented in the literature remain somewhat contradictory between supporters of a common cerebral organization of the language areas of the brain in bilingual persons and those who think otherwise.

For a long time, neurosurgeons have used cortical and subcortical stimulations in the treatment of epilepsy or brain tumor to preserve language function. Although this method has been used intensively in this field, stud-
Organization of language areas in bilingual patients

ies of bilingual patients are scarce. Included among the pioneers of direct brain mapping techniques, Penfield and Roberts worked with patients who were bilingual in French and English, but they did not particularly study cerebral organization in these patients. Actually, they strongly advocated that bilingual persons have common language areas or pathways in the brain: “French is not subserved by one area of brain and English and Chinese by others, in spite of the fact that cases have been published of adults who lost one language and preserved another as the result of stroke or others injury to the brain.” Nevertheless, they asserted the existence of a separate language switch mechanism that controlled access to different languages.

Is direct cortical stimulation a good tool to study brain organization in bilingual patients? The technique has some limitations. We think that data collected using electrostimulation cannot answer all questions raised by the phenomena of bilingual patients. First, the cortical area studied with the aid of electrostimulation is limited to the area of craniotomy. Second, by nature, bilingualism involves many variables (age of acquisition, proficiency, and type of language) and the number of patients studied is often limited, thus also limiting statistical significance. This is also the case with other brain mapping studies. In most recent studies, regardless of the technique of brain mapping used (fMR imaging, MS imaging, or PET scanning), fewer than 12 patients were tested. Third, in studying patients with brain tumors, note that gathering a homogeneous group of bilingual patients is extremely difficult and that patients with language deficits must be excluded (recruiting bilingual patients with no language deficit was probably the most challenging task in the present study). Furthermore, the use of intraoperative brain mapping to detect essential language areas is probably different from identifying cortical areas involved in language by conducting brain activation studies. Finally, direct stimulation maps mainly the gyral surface, whereas other methods of brain mapping (fMR imaging or PET scanning) can also demonstrate the sulcal depths of language. This could lead to finding different results with these varied techniques of brain mapping. Despite these drawbacks, we think that direct brain mapping techniques remain, by virtue of their accuracy by their ability to test different language tasks in the same patient, a good tool in the study of cortical language areas in bilingual persons.

In summary, in this series we have clearly demonstrated that bilingual patients use common but also different cortical areas for different languages. We found that although cerebral representation of bilingual language could be located in the same regions, with direct cortical stimulation we were able to distinguish small language-specific areas. This was observed in word retrieval (typical anomia) as well as in other language tasks such as sentence reading and/or counting in some patients. We hypothesize that this pattern of organization could explain, at least partially, cases of differential or selective aphasia described in bilingual patients (despite the language skill studied). For example, an ischemic process could affect a common language area (Language A and B) and spare a language-specific area (Language B); both languages could be affected, but Language B less than A. Recovery patterns, influenced by speech rehabilitation and initial language proficiency, could also be affected by this organization. We also found language-specific areas in both temporal and frontal areas, a finding already noted by Ojemann and Whitaker in two patients. We acknowledge that our group of patients is not a homogeneous group in terms of language proficiency and that the number of patients is limited. These factors do not allow us to draw definitive conclusions about some elements (for example, age of acquisition) that could influence the distribution of these cortical areas. In our patients and in language testing in particular, we did not find that patients had significantly more cortical areas devoted to languages in which they were less fluent as has been suggested by others. Nevertheless, we demonstrated that even in languages with the same linguistic roots (for example, French and Occitan; Cases 3, 8, and 11) separate language areas can be found. We also found that early bilingual persons (Cases 3, 8, and 10) could also have separate cortical language areas, a finding that contradicts results of the fMR imaging studies of Kim, et al. and Hernandez, et al. A misreading
of the multiple cortical representation of different languages in some of our patients could have led to possible injury of cortical areas involved in language processing. Considering these results, bilingual patients who undergo direct brain mapping (for brain tumor or epilepsy) should be tested in both of their languages.

Conclusions

Direct cortical stimulation can be used to study the language organization in the brains of bilingual patients. In this series, we found that bilingual patients could have common but also different cortical areas for different languages in temporoparietal areas and frontal areas. In some cases, language tasks such as counting, reading, or word retrieval in different languages can be sustained by distinct language-specific cortical areas. This implies that, in patients undergoing surgery for lesions in language areas, cortical mapping should ideally be performed in all languages in which the subject is fluent and by using different language tasks.

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